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DISTRIBUTION OF SUGAR AND SOLUBLE SOLIDS IN THE MAIZE STALK

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Abstract

Limited worldwide energy sources have encouraged the search for energy alternatives such as stalk sugar in maize, *Zea Mays* L. Information on the distribution and amount of sugars and soluble solids found in maize stalks will be important if the maize plant is to be exploited for its total energy production. The objective of this study was to determine the distribution of soluble solids in the stalks of three maize hybrids. Three field plantings of five replicates were made at 4-wk intervals in 1981, 1982, and 1983. Juice was sampled from each of the first ten internodes of two plants from each plot and a Brix reading taken by hand-held refractometer. In 1983, internode samples from each node in each plot were bulked and analyzed for sugar content using High Performance Liquid Chromotography (HPLC). Significant variation for soluble solids occurred among years, hybrids, and nodes. An older hybrid, developed for the South, had stalks that tended to increase in soluble solids concentration from bottom to the top of the plant. Two more recently developed hybrids decreased in soluble solids concentration from soil level upward toward the ear node, but increased from the ear node upward. The change or difference in pattern of soluble solids gradients for the more recently developed hybrids was attributed in part to selection for increased resistance to stalk rot, which is positively correlated with sugar content.

Utilization of the sugar in the juice of maize stalks as an energy source is not a new concept. France manufactured sugars from this source in the middle of the nineteenth century (1). Although stalk juices of maize were often used to make syrup, interest in the distribution of sugars in the maize stem was not reported until 1930 by Welton et al. (12). They tested two cultivars and found that the concentrations of sugars from lowest to highest internodes were nearly equal to slightly increasing, but approximately half of the total sugars were located in the four lowest internodes.

Studies of sugar gradients and translocation of carbohydrates in the maize plant (7) were encouraged by the importance of maize as an agricultural crop. Sayre et al. (9) demonstrated that prevention of pollination resulted in a sustained accumulation of sugars in the maize stalk during the normal period of early grain filling. DeTurk et al. (5) showed that hybrids resistant to cold injury and stalk rot were also high in total sugars. The relationship between high concentration of sugar in the stalk, particularly the pith tissue, and resistance to stalk rot was later confirmed by other researchers (3, 8).

Stalk sugars as an energy source stimulated work with several maize inbreds and led Van Reen and Singleton (11) to conclude that stalk sugar content was genetically influenced. They also obtained a close correlation between Brix readings and laboratory evaluations for sucrose concentration. Campbell and Hume (2) measured soluble solids in stalk juice using a refractometer and found similarly high correlations with total sugar content. The decline in stalk soluble solids during grain fill was attributed in a later study to the translocation of metabolites from stalk to the grain (6).

Previous studies of the distribution of sugars in stalk segments (11, 12) pooled stalk segments from several sampling dates to obtain values for sugar concentration. These studies indicated maximum concentrations at about 35 days after pollination, and beyond that when pollination was prevented. However, the plants sampled were varieties (12) and inbreds (11), each showing an increasing concentration from the lower internodes toward the top of the plant. Recent evaluations (4,13) have not included data from individual nodes.

The objective of this investigation was to evaluate hybrids developed under varied environments and for different purposes to determine the distribution of soluble solids in their stalks. Since consideration is being given to the use of more recently developed hybrids for carbohydrate production, knowledge of possible changes in stalk sugar distribution due to selection for traits such as yield and stalk rot resistance will be helpful.

Materials and Methods

Three commercial hybrids representing a wide range of adaptation were chosen for this study. They are identified throughout as Hybrid A: developed in and for the Southeast; Hybrid B: developed for the southern Corn Belt, but having a broad range of adaptation; and Hybrid C: developed in the northern Corn Belt for primary use as a forage crop in that region. The hybrids were planted in five replicates, in each of three planting dates, in 1981, 1982, and 1983. Plantings were made at approximately 28-d intervals each year with the first planting occurring on 1 April, or as soon after that date as possible.

Plots were single rows, 6.1 m long with a spacing of 76 cm between rows and a density of 65 000 plants ha^{-1}. Ears were removed immediately after silking to prevent carbohydrate accumulation in the kernels, simulating conditions in a planting of a male-sterile, sweet-stalk hybrid. A Bausch

Table 1. Mean percent soluble at 6 wk after anthesis in the juice of stalks from three maize hybrids planted on three dates during 1981, 1982, and 1983.

	Planting dates			
Year	1	2	3	Mean
	%			
1981	15.0	15.2	14.8	15.0
1982	14.6	13.9	14.9	14.5
1983	13.3	13.0	13.5	13.2
Years LSD (0.01) = 0.9				
Hybrid				
A	16.1	14.7	14.7	15.2
B	13.8	14.7	15.0	14.5
C	12.9	12.8	13.5	13.1
Hybrids LSD (0.01) = 0.8				
Mean	14.3	14.0	14.4	
Planting dates LSD (0.01) = 0.5				

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and Lomb (Bausch and Lomb, Rochester, NY) hand-held refractometer was used to obtain Brix readings on the juice from a 1-cm internode section just above each of the first 10 nodes from two typical bordered plants in each plot at 42 d after anthesis. The 1-cm internode section above the first above-soil node was designated as node 1. In 1983, the remaining stalk sections of each separate internode (node) from the two plants sampled from each plot were bulked, frozen immediately, and sent to the Northern Regional Research Center (NRRC) at Peoria, IL, for analysis as a single sample from each internode (node) for each replicate.

[1] Mention of a commercial product does not constitute endorsement by USDA.

Frozen samples were packed in dry ice for shipment to NRRC. For the HPLC analyses, frozen stalk sections received at NRRC were split lengthwise and then freeze-dried in a VirTis[1] sublimator (Model 100-SRC, VirTis Company, Inc., Gardiner, NY). Subsequently, these dried sections, containing about 10 g kg^{-1} moisture, were ground in a Thomas-Wiley[1] mill (Model ED-5) with a sieve containing 1-mm diam. perforations. A representative 2.0-g sample (dry solids basis) was shaken 120 min. at room temperature, in 25 mL of 50% aqueous ethanol (v/v). The mixture was then centrifuged 10 min. at 10 000 rpm. The supernatant was subsequently analyzed for sugar (glucose, fructose, and sucrose) content by HPLC using a BioRad HPX-42[1] size-exclusion column and water for the mobile phase. Preliminary anal-

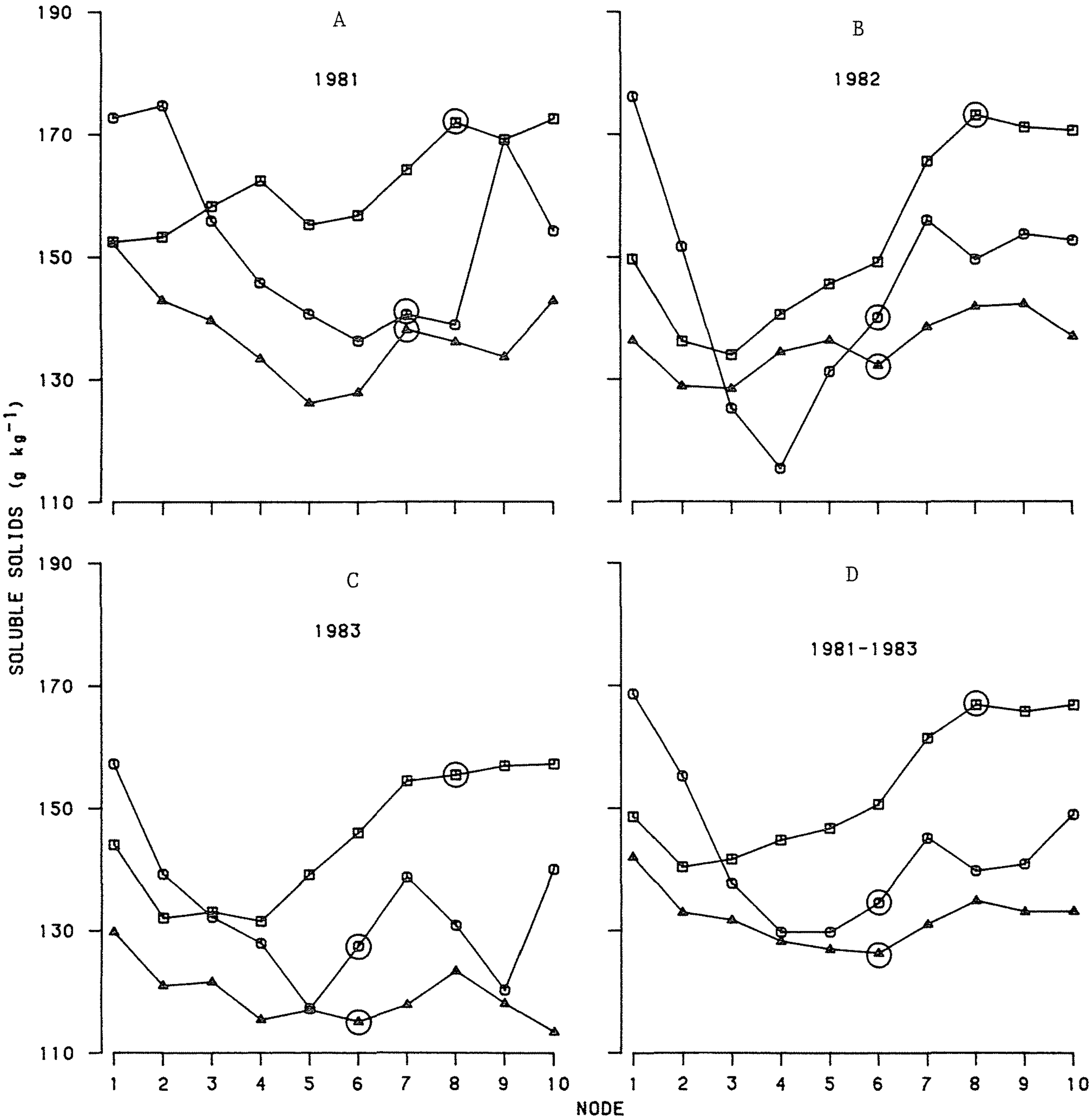

Fig. 1. Distribution of soluble solid concentrations in the stalks of three maize hybrids grown for 3 yr. □-□ = Hybrid A, ♀-♀ = Hybrid B, and ⧐-⧐ = Hybrid C. Large circles at node six, seven, or eight indicate most frequent ear-bearing node. The average SE of data points in Fig. 1A, 1B, 1C, and 1D are 4.3, 4.7, 4.2, and 2.5 g kg^{-1}, respectively.

yses determined that these procedures were sufficient to remove essentially all sugars from the stalk samples and that no significant amount of any sugars other than glucose, fructose, and sucrose were in the extracts.

The 1983 percent sugar values for nodes within plots on a dry-weight basis were transformed to angle arcsin (percentage)$^{1/2}$ for analysis and comparison, with percent soluble solids in the juice as given by refractometer readings. Comparisons were made among means by using the Waller-Duncan Bayesian k-ratio t-test described by Steel and Torrie (10).

Results and Discussion

Two-tailed F-tests on the errors of the analyses of variance for planting dates and years indicated that error variances were homogeneous. Therefore, the analyses were combined over planting dates and years. All main effects except planting dates were significant at $P < 0.01$. Except for the information on nodes, these means are presented in Table 1.

The percent soluble solids for stalks harvested in 1983 was significantly lower than for other years. This reduction was consistent over planting dates, yet unexplained by general growing conditions during the year. The 1981 season was hot and very dry; that of 1982 was nearly ideal for growing corn, while that of 1983 was a near average year in terms of temperature and moisture.

Hybrid C was significantly lower in percent soluble solids than the other two hybrids, a condition that was consistent over planting dates and years. The hybrid's poor adaptation to the Southeast is a probable reason for its poor performance. A highly significant interaction did occur between hybrids and planting dates. Most of this interaction is due to the high performance of Hybrid A in the first planting date (Table 1). In general, the variation among means in Table 1 was not unexpected, since similar differences have been previously demonstrated (13).

The gradients of soluble solids concentrations along the stalks of individual hybrids gave the most interesting results (Figure 1A to 1D). A distinct and unique pattern for these gradients exists for each hybrid tested. The unmistakable consistency of patterns over years runs counter to conclusions by Van Reen and Singleton (11) and Welton et al. (12), who stated that sugar concentrations increase from the bottom toward the top of the plant in the first six nodes, whether or not ears were removed.

The high concentrations of soluble solids in the lower two or three nodes of Hybrids B and C in comparison to the rest of the stalk is of particular interest. With the possible exception of the first node, Hybrid A seems to follow the previously reported trends of increasing soluble solid concentrations from the bottom to the top of the plant. Decreasing concentrations definitely exist for the lower five or six nodes of Hybrids B and C (Fig. 1D). An increasing trend begins just below the ear node (Hybrid B) or at the ear node (Hybrid C).

One probable explanation for the differences in gradient concentrations from those found previously may be due to continued selection for resistance to stalk rot. The correlation of stalk rot resistance with sugar concentrations would tend to increase stalk sugar, especially in the lower nodes where stalk lodging is most prevalent. Except for node one, Hybrid A has an increasing gradient for soluble solids. This hybrid is not known for its resistance to stalk rot and was developed several years prior to Hybrids B and C.

The values given in Figure 1D are believed to reflect rather accurately the soluble solid concentrations for each hybrid as each data point represents 90 individual refractometer readings for that node and has an average standard error of 2.5 g kg^{-1}. The standard errors of individual nodes for each hybrid in 1981, 1982, and 1983 averaged 4.3, 4.7, and 4.2 g kg^{-1}, respectively. They are also believed to be indicative of the trends for sugar concentrations since our correlations between Brix readings and sugar concentrations were all significant and ranged from 0.27 to 0.50. These values are not as high as those found by Van Reen and Singleton (11) but clearly establish a close enough relationship to support the change in gradient trends that has occurred over the last three to four decades.

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